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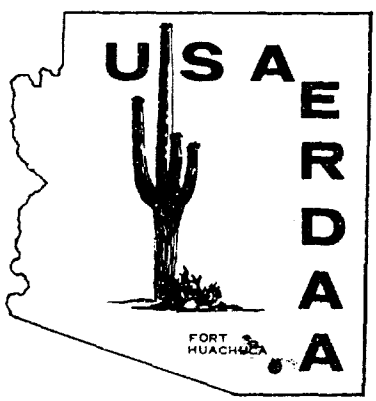
USAERDAA-MET-10-64

September 1964

An Evaluation of RADIATION COMPENSATING THERMOCOUPLE TEMPERATURE SENSORS

By. Arthur V. Carlson



Meteorology Department

U. S. Army

Electronics Research & Development Activity, Arizona

FORT HUACHUCA

HEADQUARTERS
U. S. ARMY ELECTRONICS RESEARCH AND
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USAERDAA-MET-10-64

SEPTEMBER 1964

AN EVALUATION OF RADIATION COMPENSATING THERMOCOUPLE TEMPERATURE SENSORS

by

Arthur V. Carlson

DA Task 1-G-6-50212-A-127-01/23

"Instrumentation and Techniques Improvement"

OBJECTIVE

One of the objectives of this task is to evaluate new or improved sensors or Meteorological instrumentation.

AUTHORITY

Authority for this task is contained in CDOG, paragraph 110c(1) & (2) 412a.

DIGEST

The Radiation Compensated Thermocouple (RCT) patented by Mr. Glenn E. Daniels in August 1962 is compared with a single No. 24 AWG copper constantan thermocouple sensor under conditions of exposure to solar and sky radiation. The temperature measured by the RCT is unaffected by external radiation whereas a single uncompensated thermocouple temperature sensor indicates a large increase in temperature when exposed to solar radiation even when subjected to winds up to 20 miles per hour.

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ACKNOWLEDGEMENT

The following persons conducted the field experiments discussed in this report:

Mr. Robert L. Richardson.

Mr. Robert H. Goldenberg.

Mr. Glenn R. Arnold.

LIST OF FIGURES

AN EVALUATION

of

RADIATION COMPENSATING THERMOCOUPLES

I. INTRODUCTION

1. Background:

Mr. Glenn E. Daniels, while employed in the Meteorology Department, Fort Huachuca, Arizona, invented a radiation compensated thermocouple temperature sensor (RCT) for which he received a patent in August 1962. This sensor consists of several copper constantan thermocouple junctions fabricated of different wire sizes connected in series, such that the effect of heating the sensor by radiation would be automatically eliminated.[1] Preliminary field operation tests of several models of this sensor indicated that it could be made to be insensitive to radiant heating and would measure true air temperature even when exposed in direct sunshine. Several test models of this sensor were sent to the Meteorology Division of the U. S. Army Electronic Research and Development Laboratories (USAERDL), Fort Monmouth, New Jersey, for a technical evaluation under controlled laboratory conditions. The findings of the Laboratory tests were that the models of the RCT tested were not significantly better under most conditions than a single uncompensated thermocouple made from No. 24 gauge (AWG) copper constantan wire.[2] Since these findings were not consistent with the operational performance observed with earlier models at Fort Huachuca, the test models used by USAERDL were returned to Fort Huachuca for further operational performance testing.

2. Purpose:

It is the purpose of this report to present the findings of the operational tests of the Radiation Compensated Thermocouple Temperature Sensor which were conducted at Fort Huachuca.

---

1. NASA Report "Measurement of Gas Temperature and the Radiation Compensating Thermocouple" by Glenn E. Daniels.

2. USAERDL Report "Evaluation of Radiation Compensating Thermocouples," dated June 1963.

II. SUMMARY

The Radiation Compensated Thermocouple Temperature Sensor and a single No. 24 gauge (AWG) copper constantan thermocouple were exposed to various conditions of solar and sky radiation. The outputs of both sensors were simultaneously and continously recorded on a recording potentiometer on the same chart. Results of these tests show conclusively that:

a. A single No. 24 (AWG) copper constantan thermocouple indicates temperatures several degrees higher when exposed in direct sunshine, than when shaded. This difference in temperature exists even at wind speeds up to 20 miles per hour.

b. The temperatures indicated by a properly designed Radiation Compensated Thermocouple are the same when the sensor is shaded as when it is exposed in direct sunshine.

c. The single thermocouple, when properly shielded in an instrument shelter or other shield, indicates, in general, the same temperature as the Radiation Compensated Thermocouple exposed to the sun.

d. The radiation effect on a single No. 24 gauge (AWG) copper constantan thermocouple is much greater if the connecting leads are exposed to the radiation than if they are shaded and only the sensor junctions are exposed.

III. DISCUSSION

1. Design Characteristics:

Four models of the RCT were used in these tests. Each was a five junction assembly consisting of a different combination of wire sizes as follows:

Type I, AWG Nos. 26, 16, 20, 16, 26.
Type II, AWG Nos. 28, 20, 24, 20, 26.
Type IV, AWG Nos. 24, 20, 22, 20, 24.
Type VII, AWG Nos. 26, 20, 24, 24, 28.

According to empirical data obtained at Fort Huachuca on the relative amount of heating by radiation corresponding to each wire size, it was computed that the following degree of compensation would be obtained with each of the above designs:

Type I -- 90%
Type II -- 100%
Type IV -- 50%
Type VII -- 70%

The physical construction of the Type II RCT and the single thermocouple sensors used in this test is shown in Figure 1. All the junctions were butt joined and silver soldered, such that the sensor cross section is uniform and continuous across the junction.

2. Test Procedure:

The Radiation Compensated Thermocouple Sensor and a single thermocouple sensor were exposed together on the roof of Greely Hall at Fort Huachuca, Arizona. (See Figure 2.) Outputs of both sensors were simultaneously recorded on a two pen recording potentiometer (see Figure 3) in the Standards and Calibration Laboratory of the Meteorology Department.

Sensor recordings were made for various combinations of exposure, which included:

a. Both sensors exposed to the sun. (See Figure 4.)
b. Both sensors exposed inside a standard type weather instrument shelter. (See Figure 5.)
c. Each sensor alternately exposed outside the shelter with the other exposed inside the shelter.

The above tests were conducted during day and during the night, and also during both clear and cloudy weather under a variety of wind conditions.

The sensors were always mounted in a horizontal position pointing toward the north when exposed outside the shelter. Approximately two feet of the lead wires which connect the sensors to the recorder were also exposed during the tests such that the lead wires adjacent to the thermocouple sensors were subjected to the same radiation as the sensor junctions.

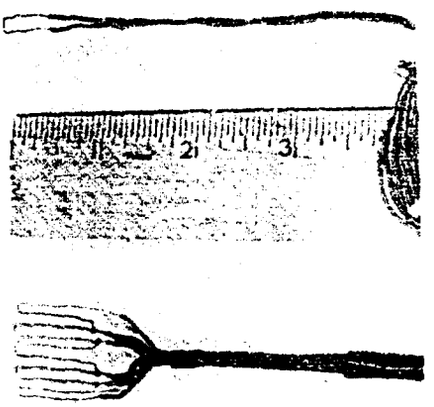


Fig. 1. Comparison of Radiation Compensated Thermocouple (bottom) with Single Uncompensated No. 24 (AWG) Copper Constantan Thermocouple.

Fig. 2. Test Site on Roof of Greely Hall, Fort Huachuca, Arizona

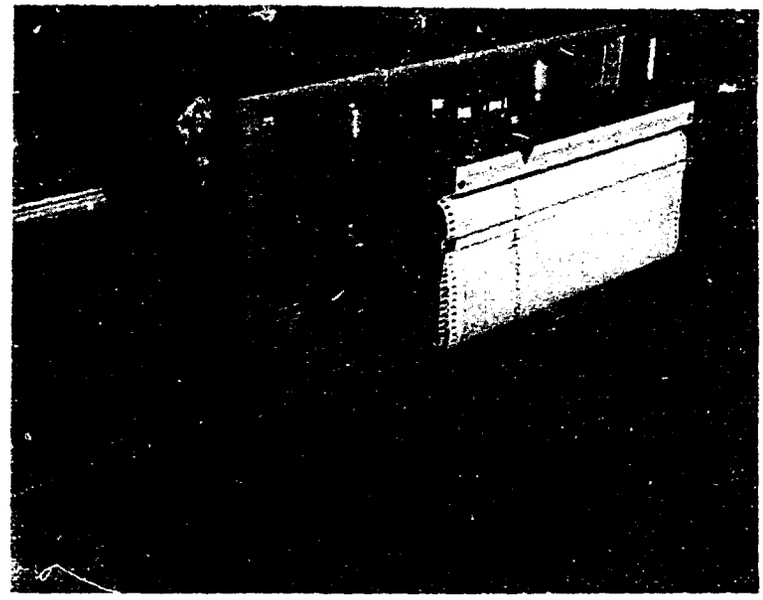


Fig. 3. Two Pen Recording Potentiometer Used to Record Output of Sensors.

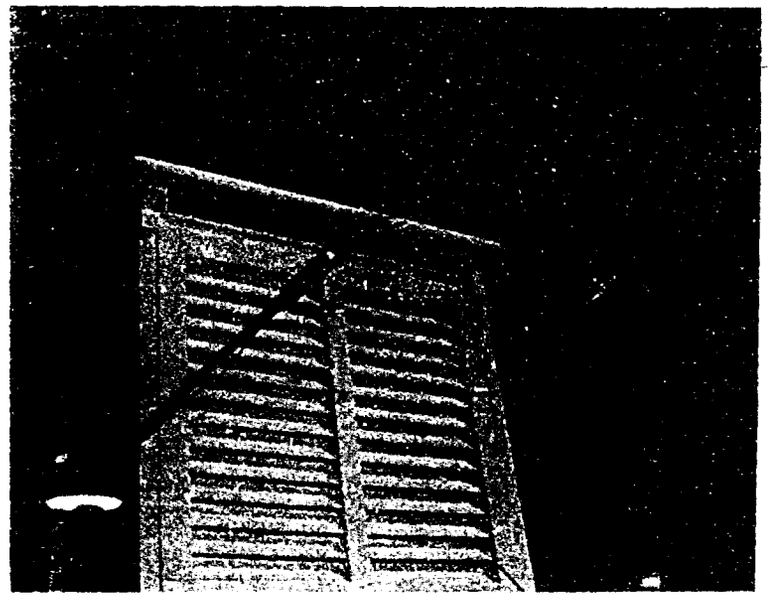


Fig. 4. Radiation Compensated Thermocouple and a Single Thermocouple Exposed to Solar Radiation.

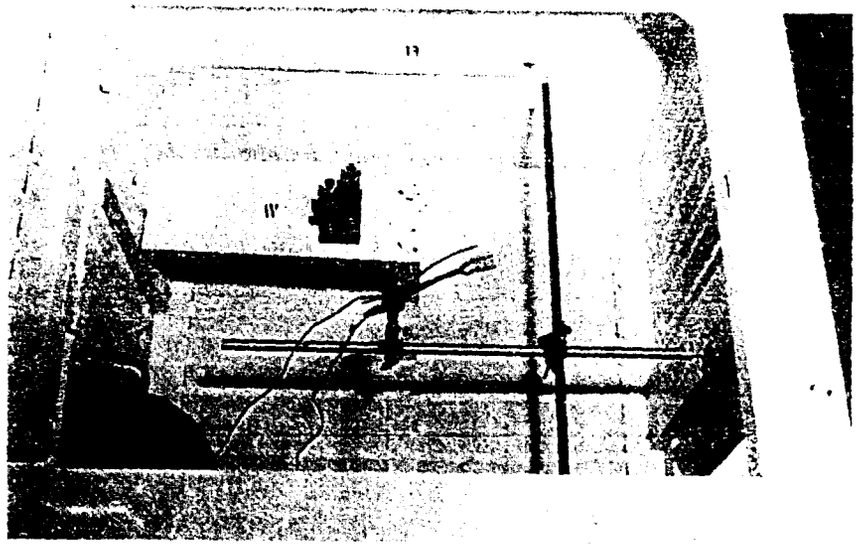


Fig. 5. Radiation Compensated Thermocouple and single Thermocouple Exposed Inside an Instrument Radiation Shield.

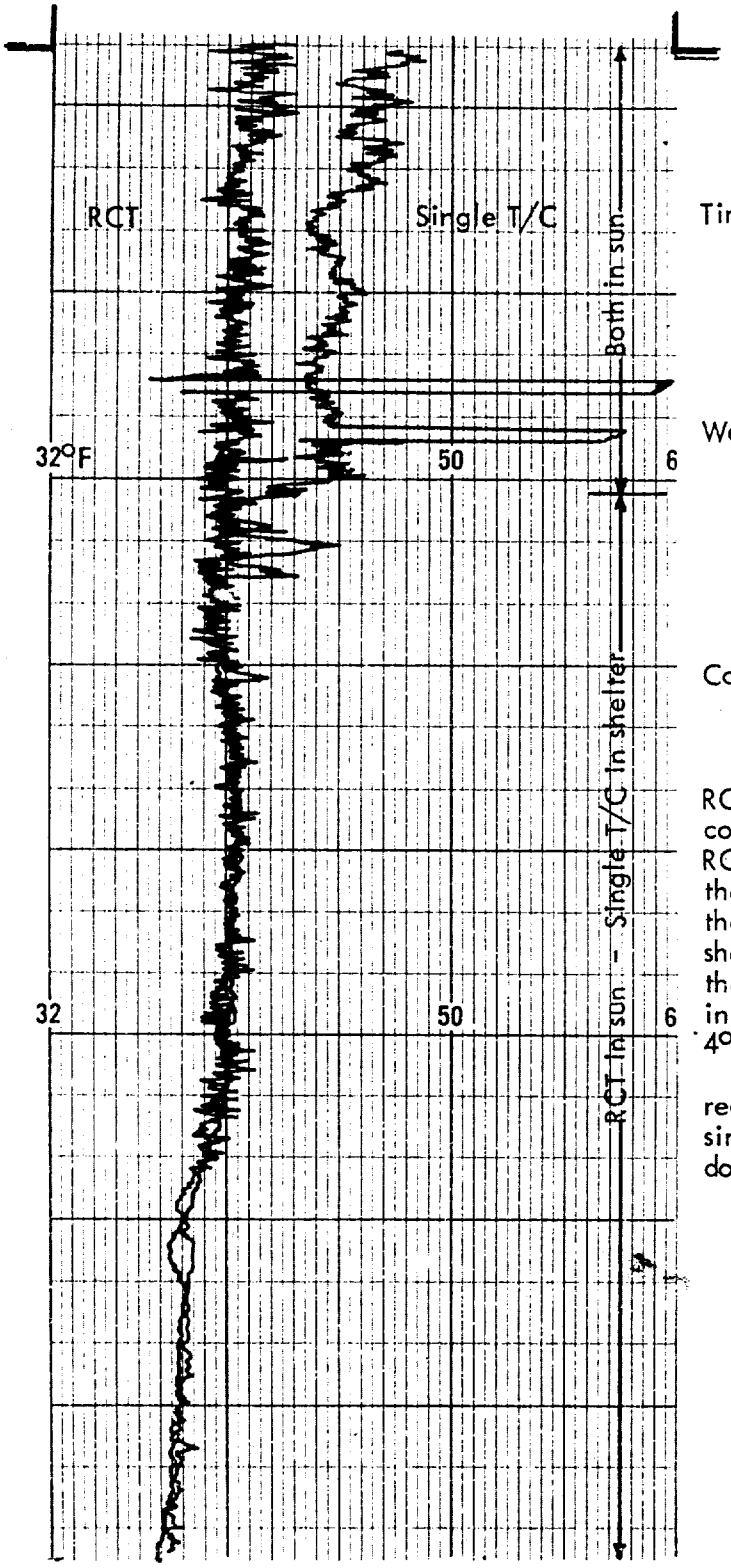
IV. TEST RESULTS

1. The results of the tests show that Radiation Compensating Thermocouple No. 2 effectively compensates for radiation under all conditions encountered in these tests. RCT designs 1, 4, and 7, as anticipated, did not completely compensate for radiation.

2. In general, the RCT exhibited more frequent flucuations in its temperature record than the single uncompensated thermocouple sensor. The magnitude of these flucuations was greatest for RCT design No. 1, and was least for RCT design No. 2. The flucuations in all designs were greater during light winds than during strong winds. However, the RCT design No. 2, which consists of sensor wires of nearly uniform sizes, exhibited no flucuations which would prohibit its use as an operational temperature sensor.

3. The single uncompensated No. 24 (AWG) thermocouple sensor exhibited significant radiation heating when exposed to solar radiation under all winds encountered in the tests. Two to three degrees Fahrenheit of radiation heating was maintained even in winds in excess of 15 miles per hour. This heating effect is much greater than was observed during USAELRDL tests at Fort Monmouth. The reason for different results obtained at Fort Huachuca and Fort Monmouth is probably due to the different exposure used. At Fort Monmouth the radiation source illuminated a spot only approximately 3/4 inches in diameter: thus, only the sensor junction was subject to radiation. Under such conditions the heat obsorbed by the sensor junction would be rapidly carried away from the junction by conduction along the relatively cooler lead wires. At Fort Huachuca the entire sensor assembly, including approximately two feet of lead wire, was exposed to the sun (this is normal field installation). In this case the entire assembly becomes heated, and heat absorbed by the sensor junction cannot be conducted away along the lead wires. Figure 15 illustrates the effect on the temperature indication of a single No. 24 gauge (AWG) thermocouple when the lead wires are exposed to the solar radiation. When the leads are shaded and only the sensor junctions are exposed to the radiation the temperature increase due to radiation is only approximately 20% of the increase obtained when the leads are exposed also.

4. Temperature recordings obtained during the tests of RCT design No. 2 are shown in the following figures. A discussion of performance and a description of test conditions are presented with each record. It should be noted that the two pens on the recorder used in these tests are physically displayed approximately 4 millimeters to permit the pens to pass each other during operation. Therefore, the two temperature records shown on each chart are out of phase by 4 millimeters, or approximately two minutes in time.



RCT TYPE # 2

Time:

0730 - 0900 hours

26 Feb 64

Weather:

Clear

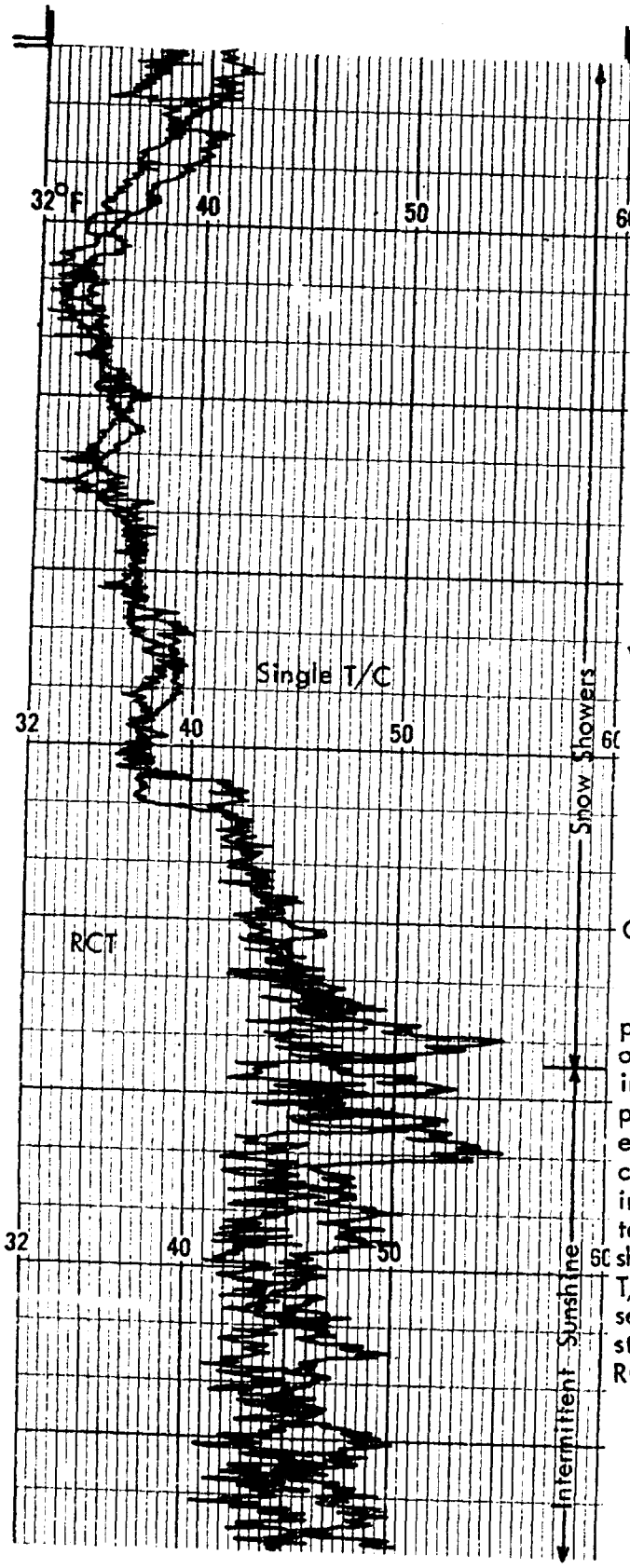
Wind 10 - 15 mph

Comments:

This record shows that type #2 RCT provides practically perfect compensation characteristics. The RCT exposed to the sun indicates the same average temperature as the single T/C exposed inside the shelter. When moved into the sun the single T/C shows an increase in temperature of approximately 4°F.

NOTE: Although the wind reaches 15 mph, the heating of the single T/C due to solar radiation does not become less than 2°F.

Fig. 6



RCT TYPE # 2

Time:

1000 - 1130 hours

26 Feb 64

Exposure:

Single T/C outside

RCT outside

Weather :

Snow showers

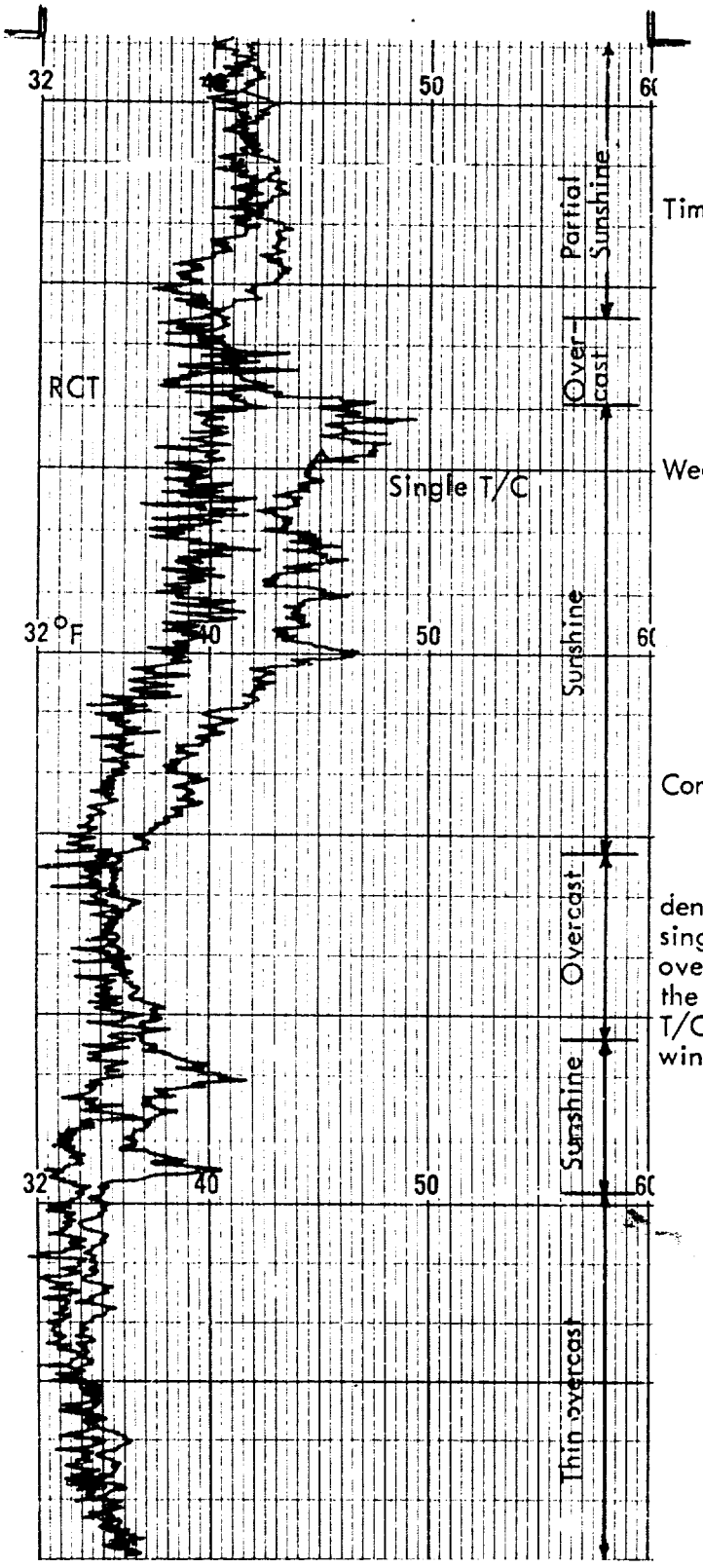
Intermittent sunshine

Wind 15 - 25 mph

Comments:

This record shows the typical performance of the RCT type #2 operating outside the shelter on an intermittently cloudy day as compared to a single T/C similarly exposed. During periods when clouds obscure the sun both sensors indicated practically the same temperature. When the sun was shining on the sensors, the single T/C indicated temperatures several °F higher. This demonstrates the effectiveness of the RCT insensitivity to solar radiation.

Fig. 7



RCT TYPE #2

Time:

1210 - 1340 hours

26 Feb 64

Weather:

Intermittent clouds and sunshine

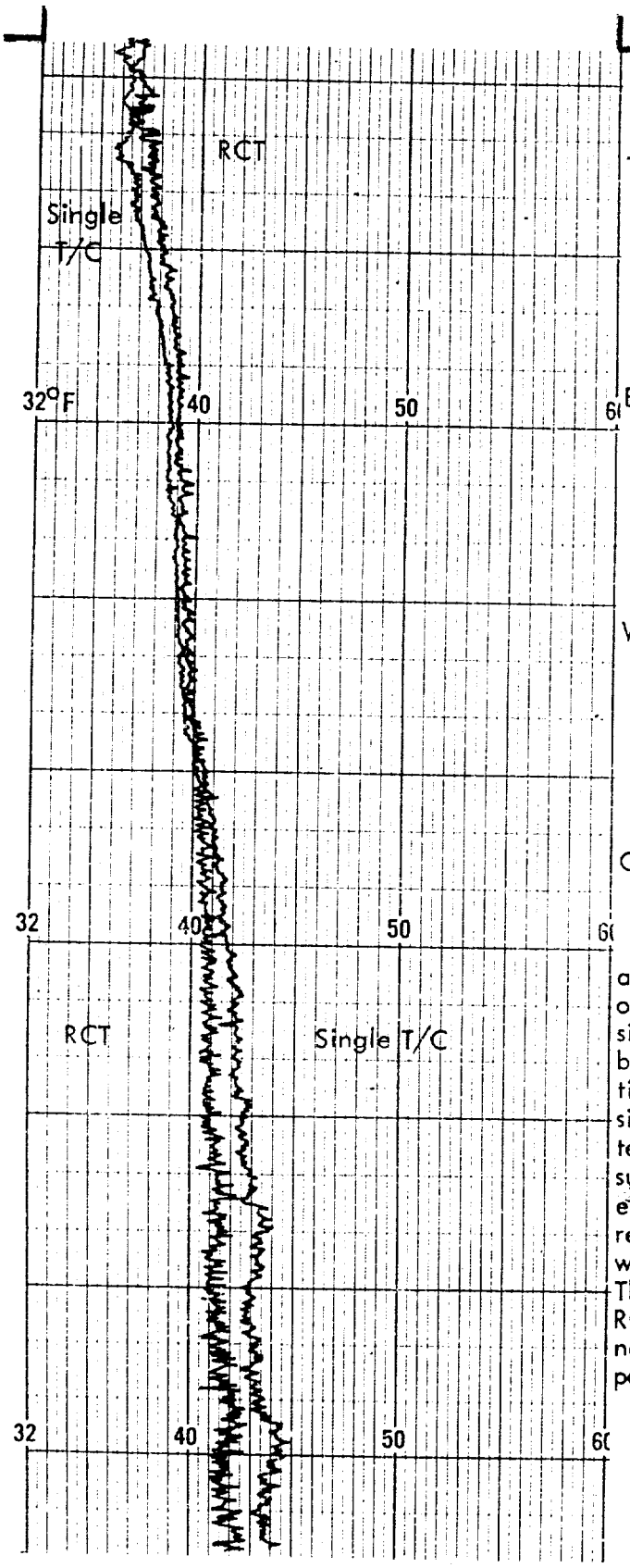
Snow showers

Wind 15 - 22 mph

Comments:

This record also shows coincident temperature traces from the single T/C and the RCT only during overcast periods. It also shows that the radiation effect on the single T/C is still appreciable at 22 mph winds.

Fig. 8



RCT TYPE # 2

Time:

1710 - 1840 hours

26 Feb 64

Exposure:

Single T/C outside

RCT outside

Weather:

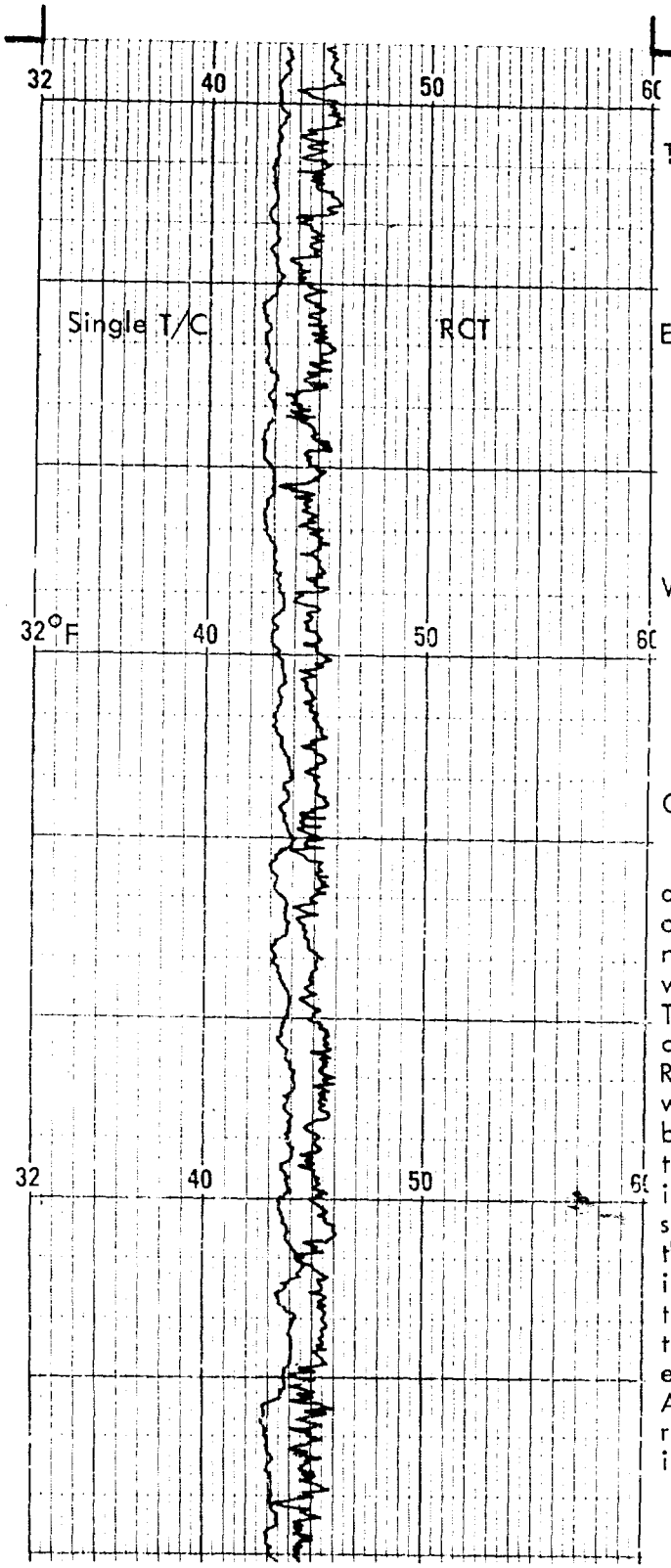
Clear

Wind - 15 mph

Comments:

This record shows the performance of the RCT type #2 operating outside the shelter, compared to a single T/C similarly exposed under both positive and negative radiation conditions. Before sunset the single T/C indicated a higher temperature than the RCT and after sunset, it indicated a lower temperature. After sunset, instead of receiving radiation, the sensors were radiating to a colder sky. This shows qualitatively that the RCT effectively compensates for negative radiations, as well as positive.

Fig. 9



RCT TYPE #2

Time:

2000 - 2130 hours

24 Feb 64

Exposure:

Single T/C inside

RCT outside

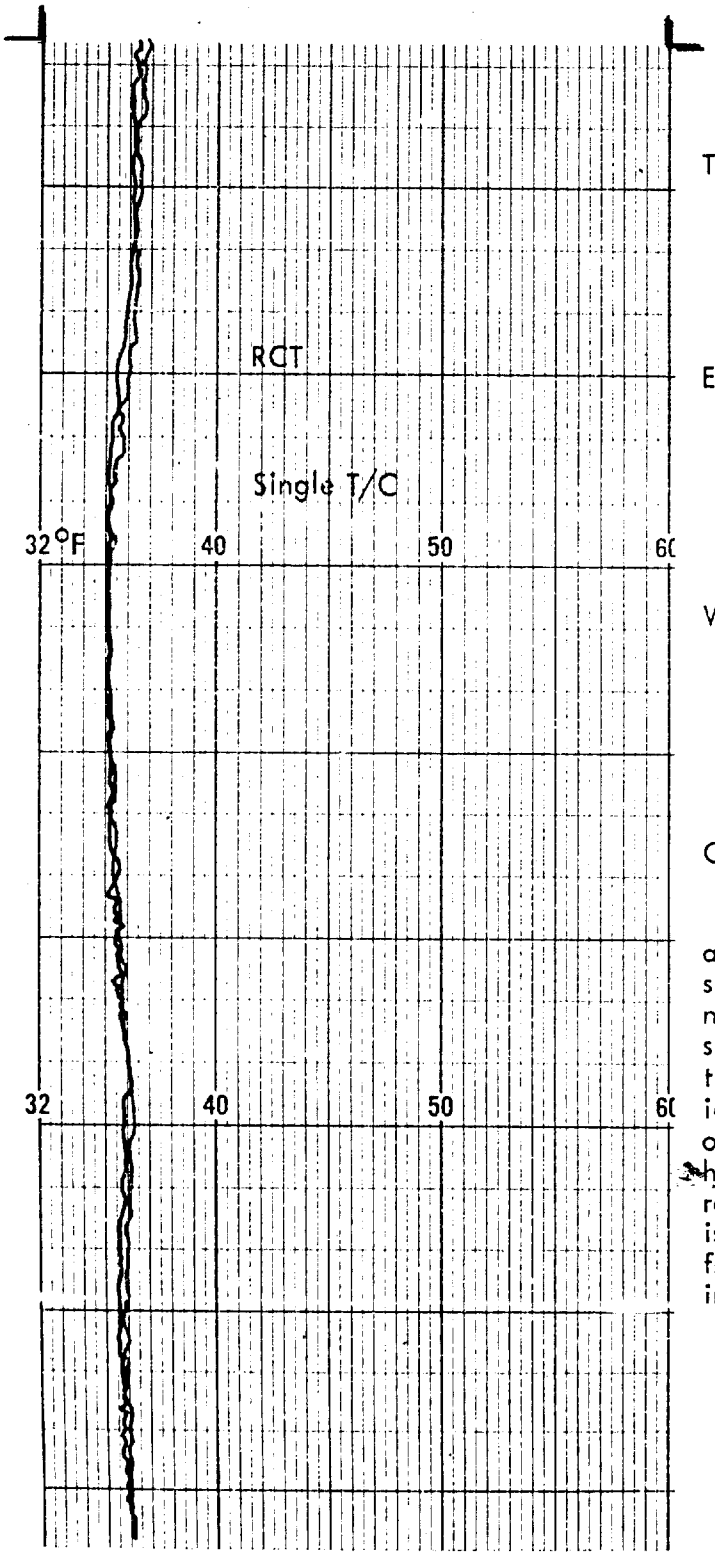
Weather:

Clear -- calm

Comments:

This record shows the performance of the RCT type #2 exposed outside the shelter on a calm, clear night, compared to the single T/C which is exposed inside the shelter. The single T/C consistently indicates a lower temperature than the RCT. It is hypothesized that the walls of the instrument shelter cool below ambient temperature by radiation to a cold sky. The cool walls in turn absorb radiation from the sensors and air inside. Therefore, the single T/C inside the shelter indicates a lower temperature. If this hypothesis is correct, such a temperature difference would not exist on a cloudy night. See Fig 11. Also, a similar recording would result if both sensors were exposed inside the shelter. See Fig 12.

Fig. 1



RCT TYPE #2

Time:

2000 - 2100 hours

29 Feb 64

Exposure:

Single T/C inside

RCT outside

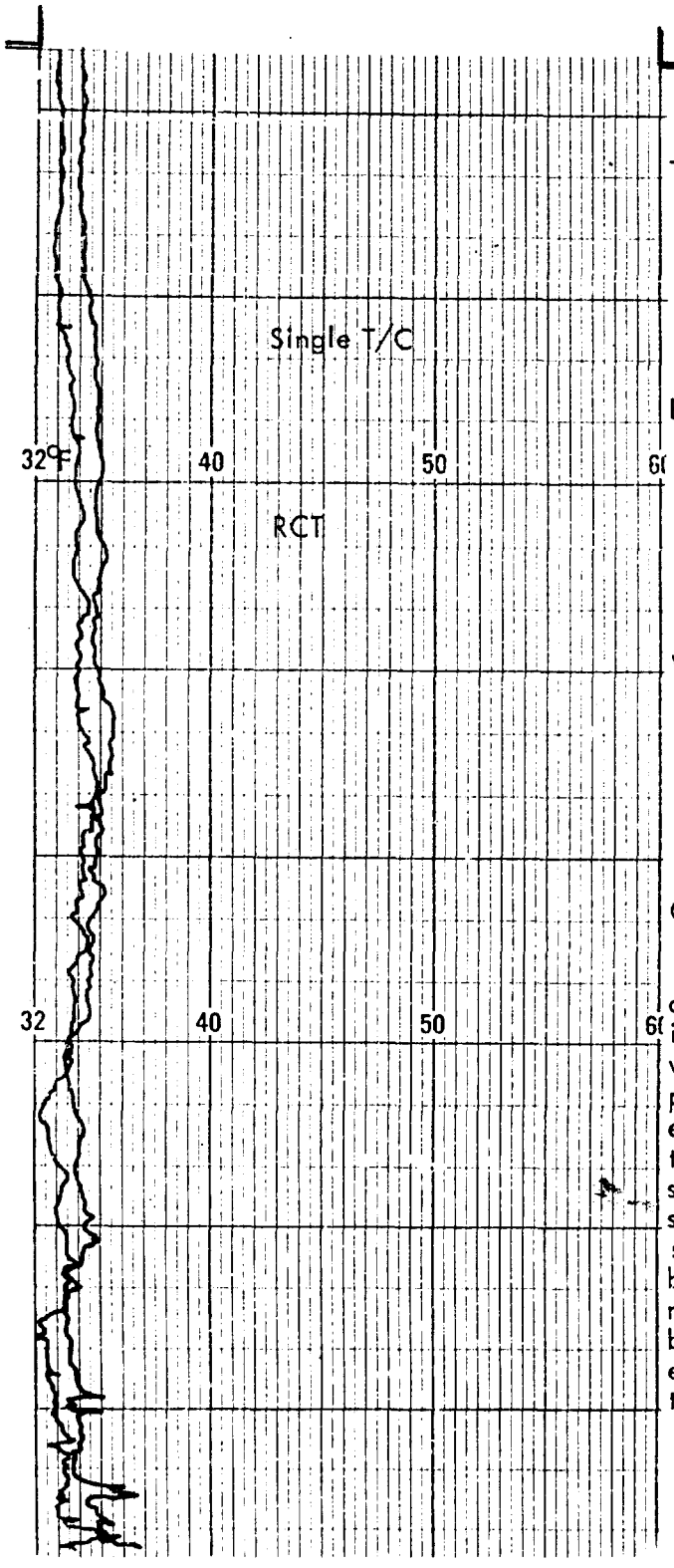
Weather:

Broken - scattered clouds
6000' - 13,000'
Wind - 12 - 15 mph

Comments:

This record shows the performance of RCT type #2 exposed outside the shelter on a windy, cloudy night compared to a single T/C inside. Here the temperature indications of both sensors are almost identical. In this case, because of the clouds, the sky is not a cold heat sink so the shelter cannot radiate heat to the sky. Thus, there is no significant radiation to or from the sensors, and both sensors indicate the true air temperature.

Fig. 11



RCT TYPE #2

Time:

2345 -- 0115 hours

4 - 5 Mar 64

Exposure:

Single T/C inside

RCT inside

Weather:

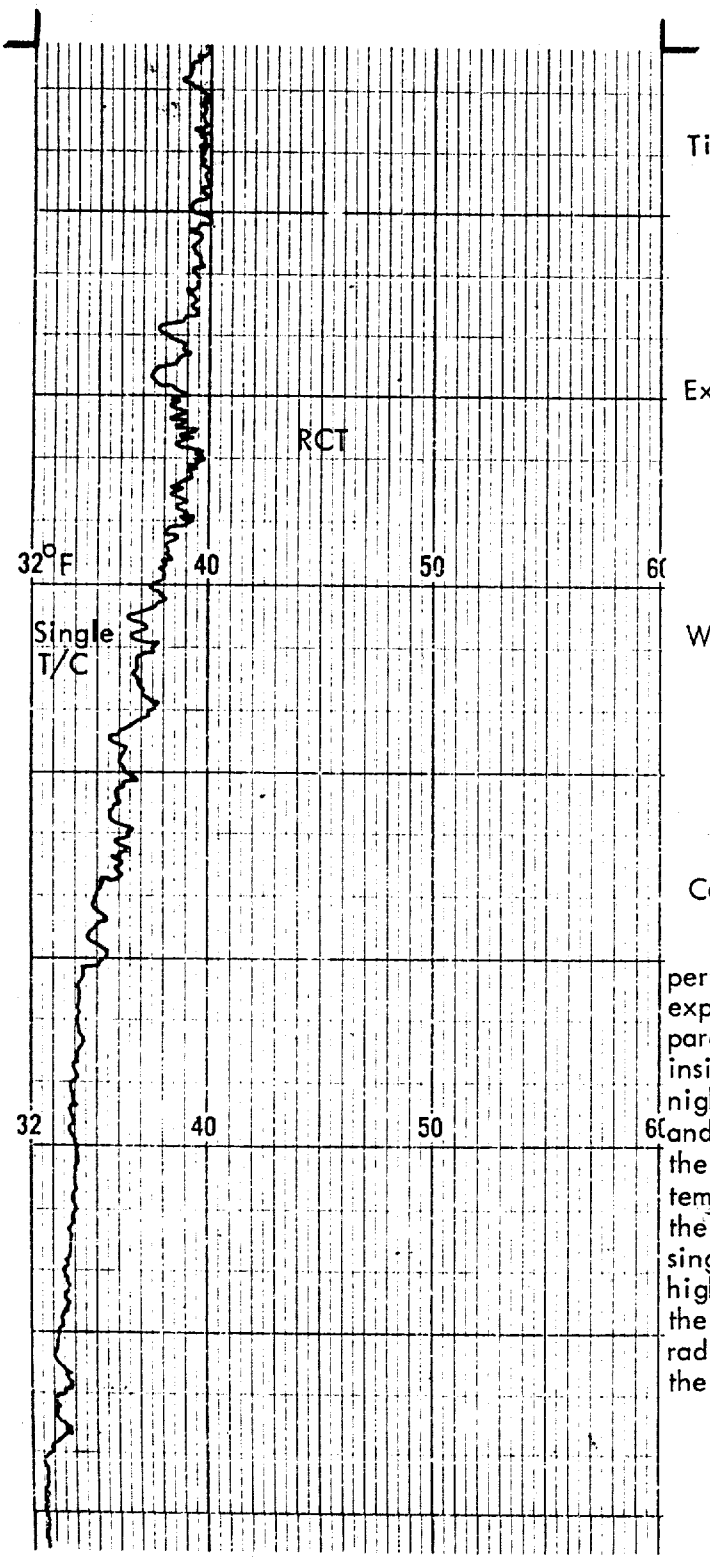
Clear

Wind 5 - 6 mph

Comments:

This record shows the performance of the RCT type #2 exposed inside on a clear night compared with a single T/C similarly exposed. The single T/C consistently indicated a lower temperature than the RCT. This further supports the hypothesis that the sensors are radiating heat to the shelter walls which are cooled below ambient air temperature by radiation to a cold sky. The RCT, being insensitive to this radiation effect, indicates a higher temperature.

Fig. 12



RCT TYPE #2

Time:

0800 hours

1 Mar 64

Exposure:

Single T/C inside

RCT outside

Weather:

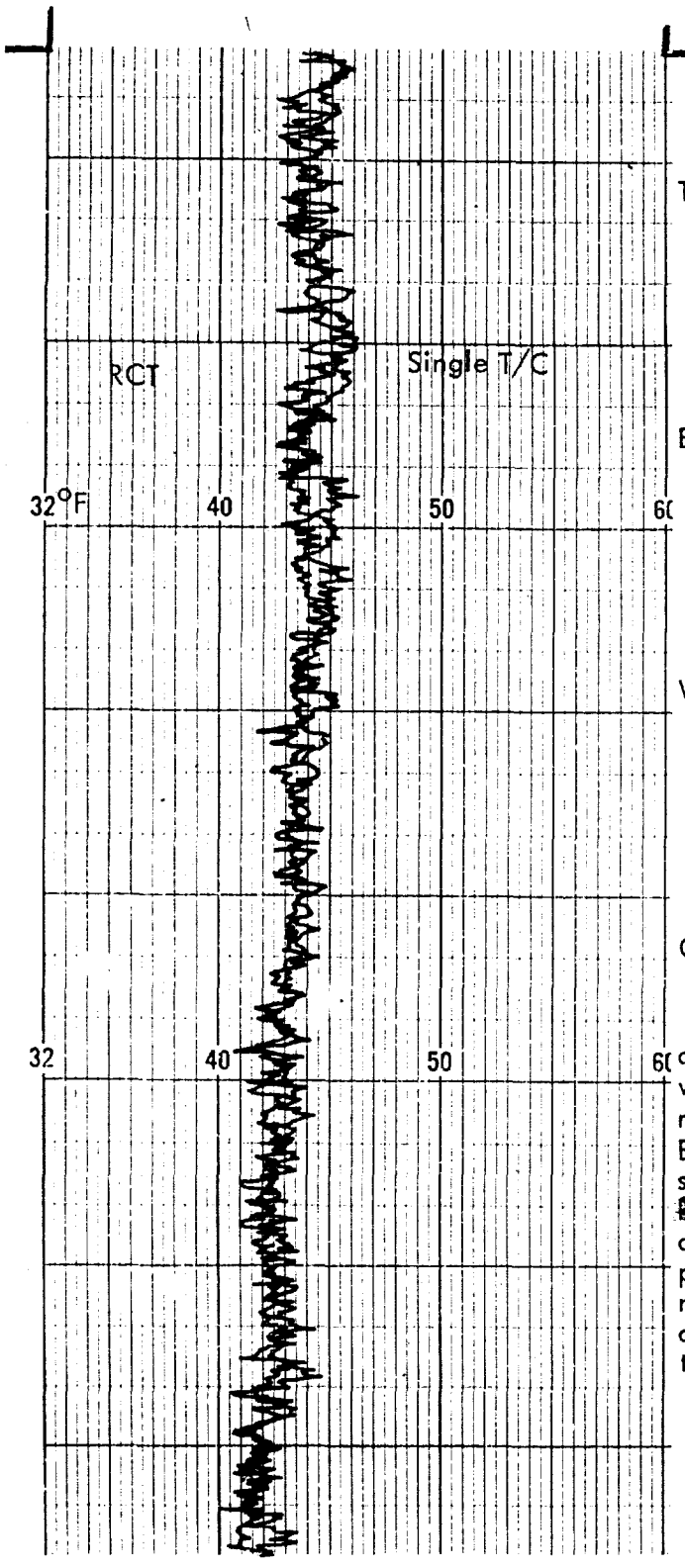
Clear

Wind -- 3 mph

Comments:

This record shows the performance of the RCT type #2 exposed outside the shelter, compared to a single T/C exposed inside during the transition from night to day when the sky is clear and winds are light. Here again the single T/C indicates a lower temperature than the RCT during the night, but after sunrise the single T/C gradually indicates higher temperatures as the walls of the shelter heat up from solar radiation. This further supports the hypothesis proposed for Fig 10.

Fig. 13



RCT TYPE #2

Time:

1300 - 1430 hours

4 Mar 64

Exposure:

Single T/C inside

RCT inside

Weather:

Clear

Winds 12 - 17 mph

Comments:

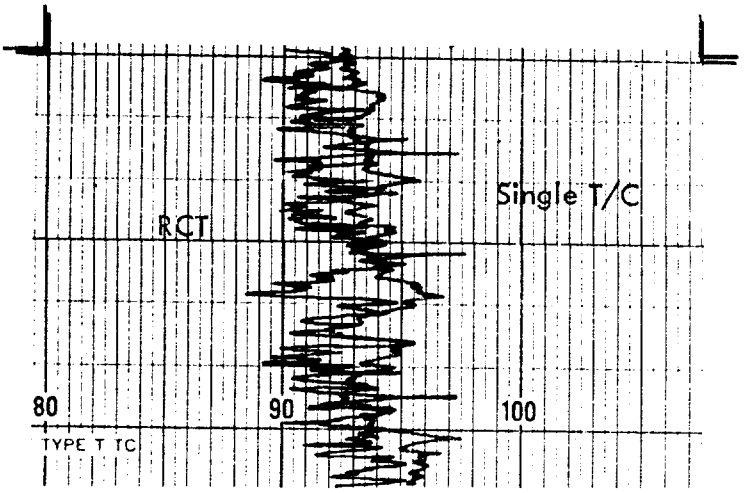
This record shows the performance of the RCT type #2 exposed with a single T/C inside an instrument shelter on a clear, windy day. Both sensors indicate practically the same temperature. Apparently because of the wind the shelter walls are maintained at ambient air temperature and, thus, the sensors are not subject to radiation effects, and both sensors indicate the true air temperature.

Fig. 14

Effect of Exposed Lead Wires on Radiation Heating

of a Single No. 24 AWG Copper Constantan and

the RCT Thermocouple Temperature Sensors



Sensor Junctions only
Exposed to Solar Radiation

RCT TYPE #2

Time:

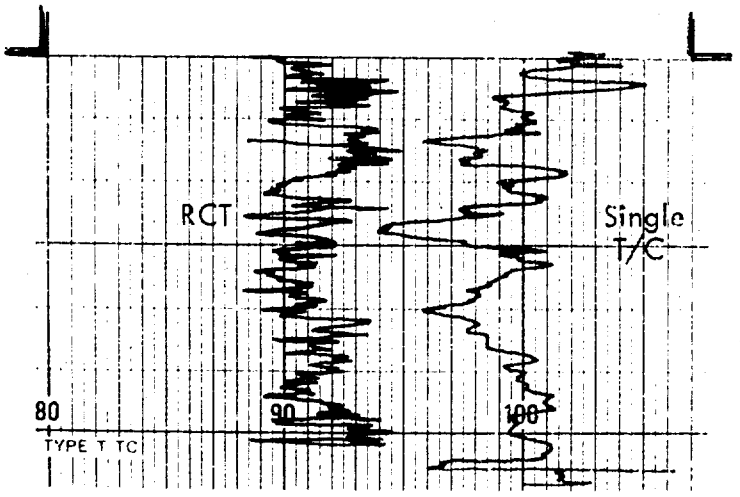
1430 hours

23 June 1964

Weather:

Clear

Wind 6-7 mph



Sensor Junctions and Connecting

Leads Exposed to Solar Radiation

Comments:

These records show that the heating effect of solar radiation on a single 24 AWG Copper Constantan Thermocouple is several degrees higher when the connecting lead wires are also exposed to solar radiation.

Fig. 15

V. CONCLUSIONS

1. The RCT effectively compensates for radiation heat effects on the measuring sensor under all types of exposure encountered in these tests.

2. A single No. 24 (AWG) thermocouple temperature sensor has significant radiation errors when exposed outside a radiation shield either in the daytime or at night. The magnitude of the radiation errors is much less when the lead wires are shielded from radiation during exposure of the sensor junction to radiation.

VI. RECOMMENDATIONS

1. It is recommended that the Radiation Compensated Thermocouple be considered as a replacement for meteorological thermocouple temperature sensors now in use where simpler installation and better performance are needed.

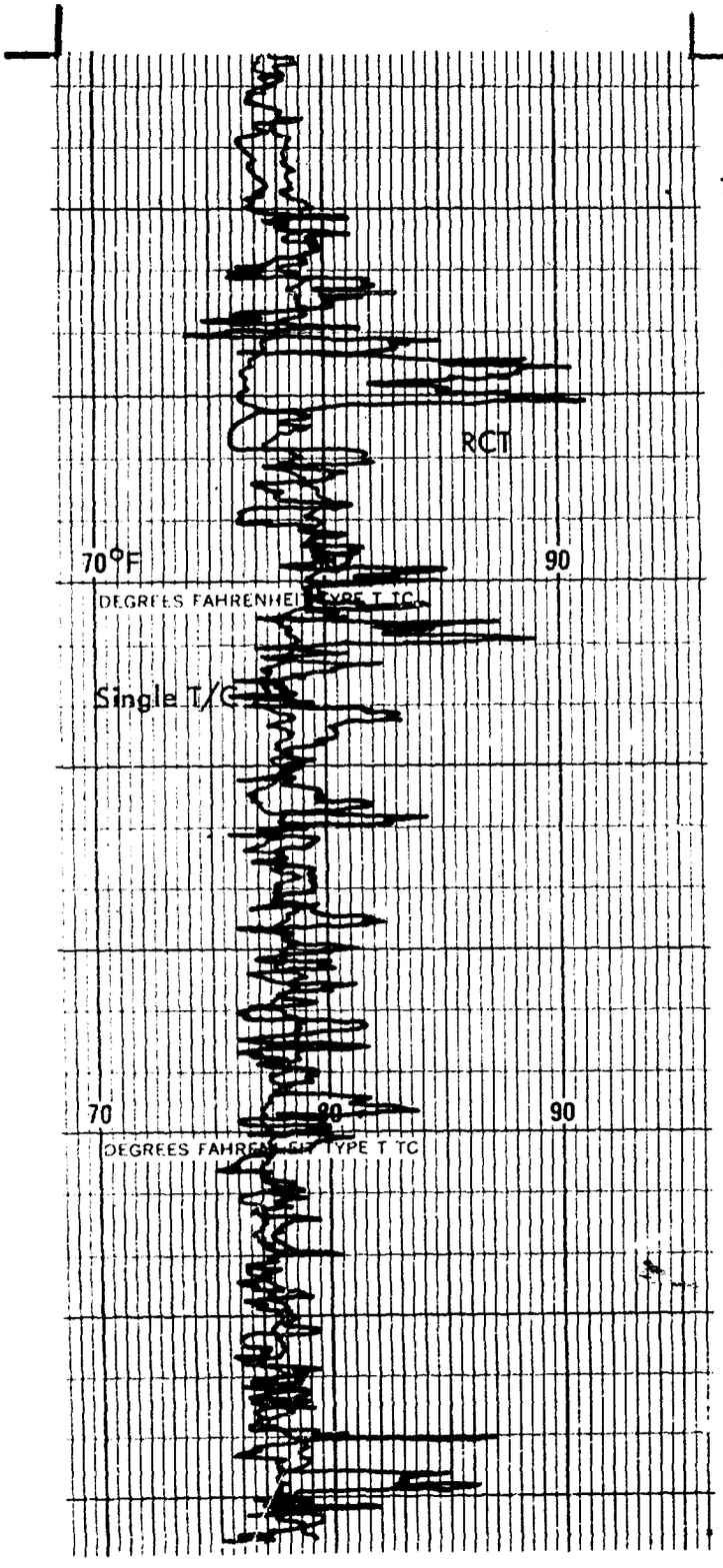
2. It is recommended that the Radiation Compensated Thermocouple be considered for the measurement of surface or near surface temperatures where shields interfere with effective temperature measurement.

APPENDIX

Performance records of RCT Types 1, 4, and 7.

NOTE: These sensors were purposely designed to show the effects of improper combinations of sensor sizes.

The absolute magnitude of the increase in temperature of the sensor junctions, due to radiant heating or cooling, varies with the wind speed. Higher wind speeds carry excess heat away from the sensor more rapidly than lower wind speeds. For stable winds, the compensation is effective because the relative heating of the different junction sizes remains unchanged. In cases of exposure in rapidly varying winds, the compensation is not maintained during the transition from one wind speed to another because the rate at which each junction reaches temperature equilibrium at the new wind speed varies with the size of the wire. For example, if the wind speed suddenly increases, the effect will be to cool each sensing junction because more of the heat absorbed by radiation will be carried away by the air. However, a small junction will cool to its new equilibrium state more quickly than the large one. Thus, until the larger junction reaches its equilibrium state, the compensation will not be completely effective. This condition is most evident in rapidly fluctuating light winds where the radiation effect is large. Figure A-1 illustrates the performance of an RCT which combines widely different wire sizes.



RCT TYPE #1

Time:

1100 - 1230 hours

Exposure:

RCT outside shelter

Single T/C inside shelter

Weather:

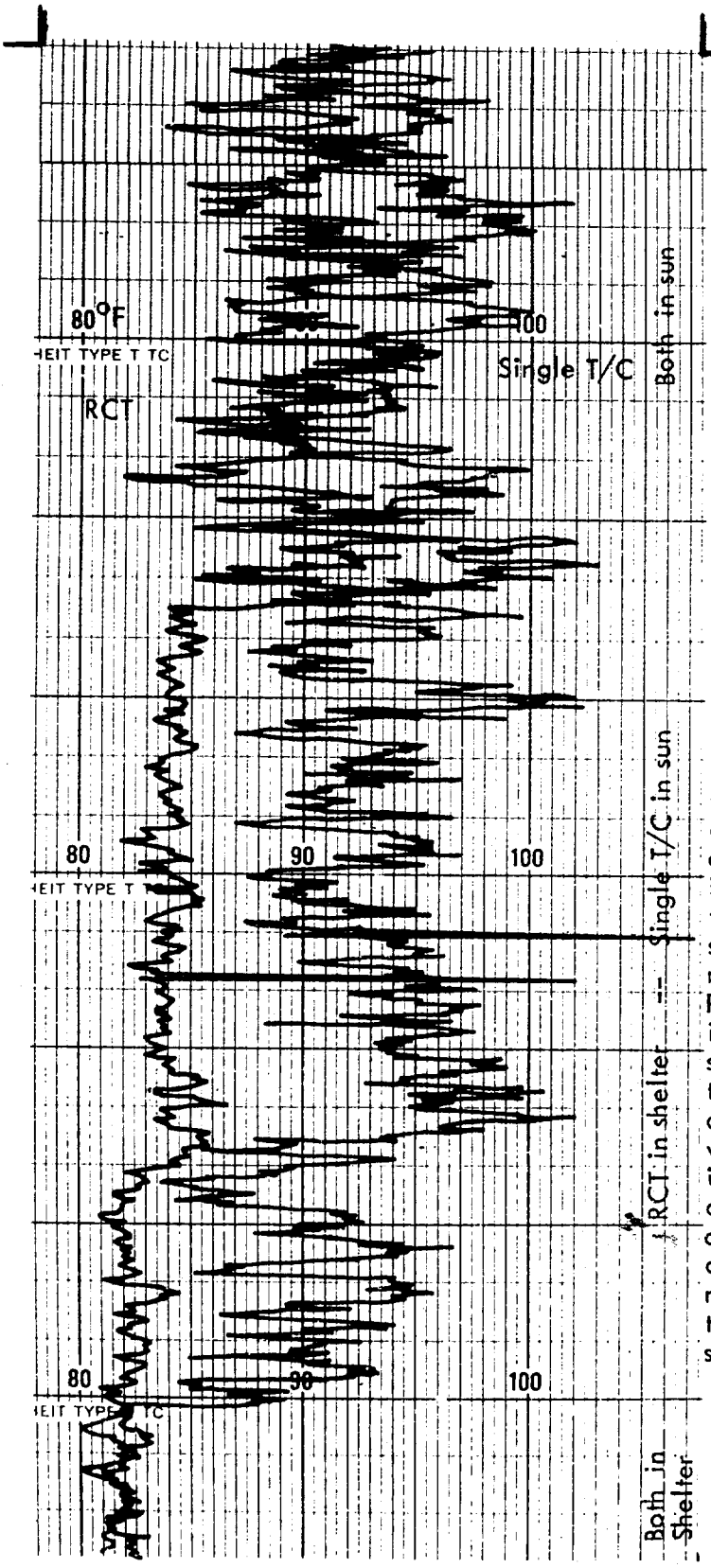
Wind approximately 3 mph

Clear

Comments:

This record shows that Type #1 RCT provides reasonably good compensation but that its temperature indication makes large oscillatory excursions. The mean values of the temperatures indicated by the RCT outside the shelter and the single T/C inside the shelter are almost the same indicating that the compensation is effective. However, because of larger differences in wire sizes used in type #1 RCT design and the low wind speeds the compensation is frequently unstable yielding erroneous temperature indications.

Fig. A-1



RCT TYPE #4

Time:

1100 - 1230 hours

11 Sept 1963

Weather:

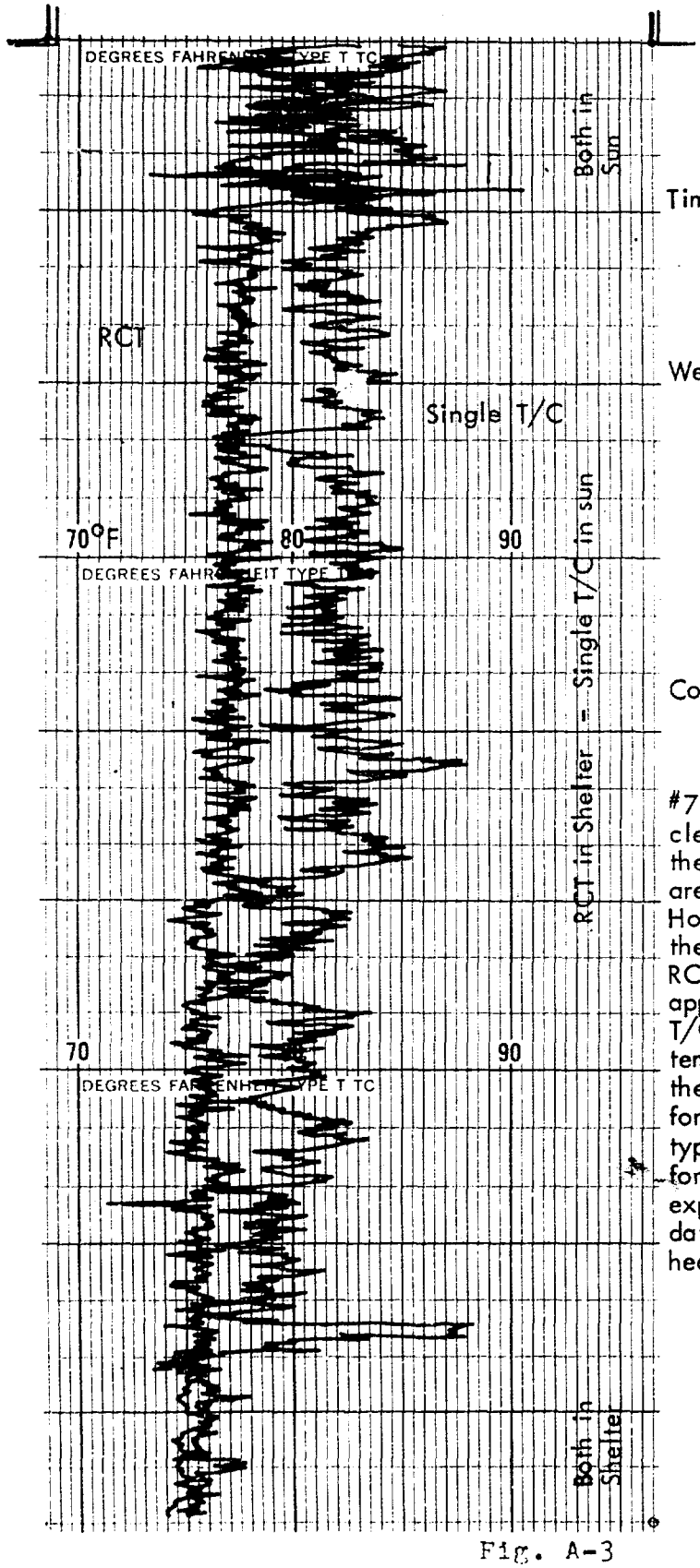
Wind - 5 mph

High thin clouds

Comments:

This record shows the performance of the RCT type #4 compared to a single T/C on a clear day. Both sensors indicated the same temperature when they were inside the shelter. When the sensors were moved outside the shelter the RCT temperature indications increased 5-6°F and the single T/C temperature indications increased 10-12°F. The degree of compensation provided by this design, therefore, is approximately 50%. This is consistent with the prediction of compensation effectiveness computed from empirical data relating the radiant heating of the T/C sensor to the sensor size.

Fig. A-2



RCT TYPE #7

Time:

0930 - 1100 hours

Weather:

Wind 7 - 10 mph

High thin clouds

Few cumulus

Comments:

This record shows RCT type #7 compared to a single T/C on a clear day. Both sensors indicate the same temperature when they are exposed inside the shelter. However, when exposed to the sun the temperature indicated by the RCT immediately increased by approximately 3°F and the single T/C at the same time indicated a temperature 7 - 8°F higher than the shelter temperature. This performance indicates that the RCT type #7 only partially compensates for radiation. It is consistent with expectations based on empirical data relating sensor size to radiant heating effect.

Fig. A-3

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